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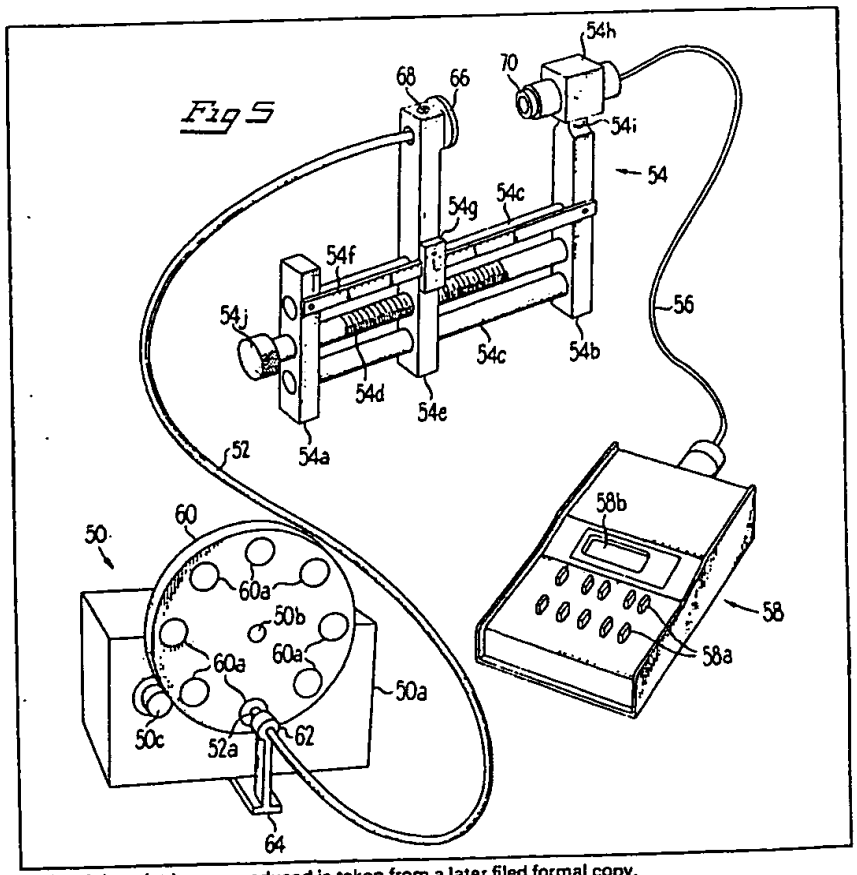
(54) Examining biological materials

(57) A device and method for the quantitative measurement of the absorption and scatter, as a function of wavelength, of biological materials, especially human tissue, utilizing light having a wavelength in the range of 400 to about 700 nanometers, and infrared light having a wavelength in the range of 700 to about 10^6 nanometers. Basically the apparatus comprises a light source, a wavelength selection means 50, a light delivery means 52 with an entrance facet 52a next to means 50, and an exit facet next to the tissue examined and a light detector 70 next to the tissue on the oposite side. Measurement is preferably in a scanning mode to produce a shadowgraph image or using multi-spectral imaging techniques in conjunction with a digital memory or an image storage tube. The apparatus and method may also be used with computer image reconstruction like that of computerized axial tomography. Embodiments for examining human breasts are described.



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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

Fig 1

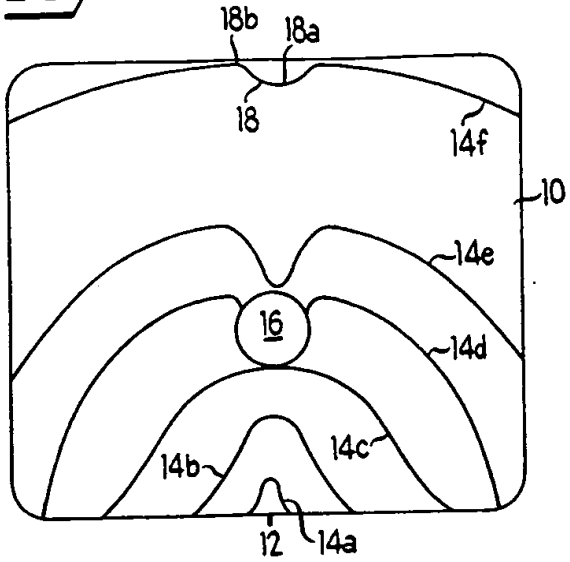


Fig 2

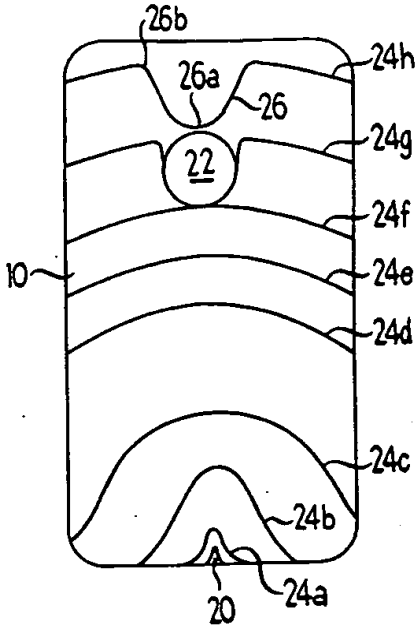


Fig 3

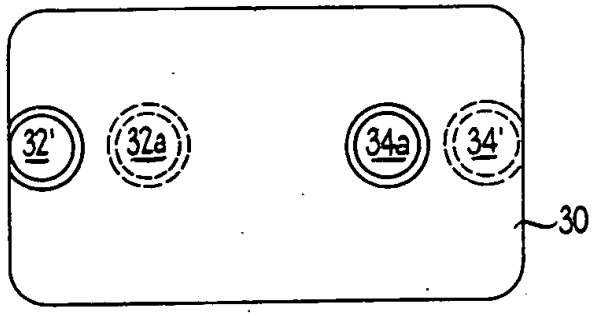


Fig 4

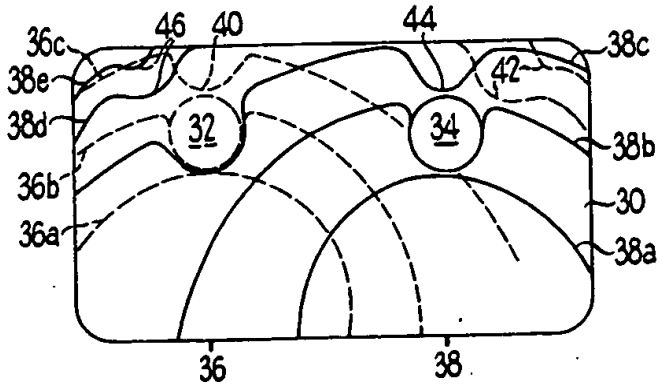
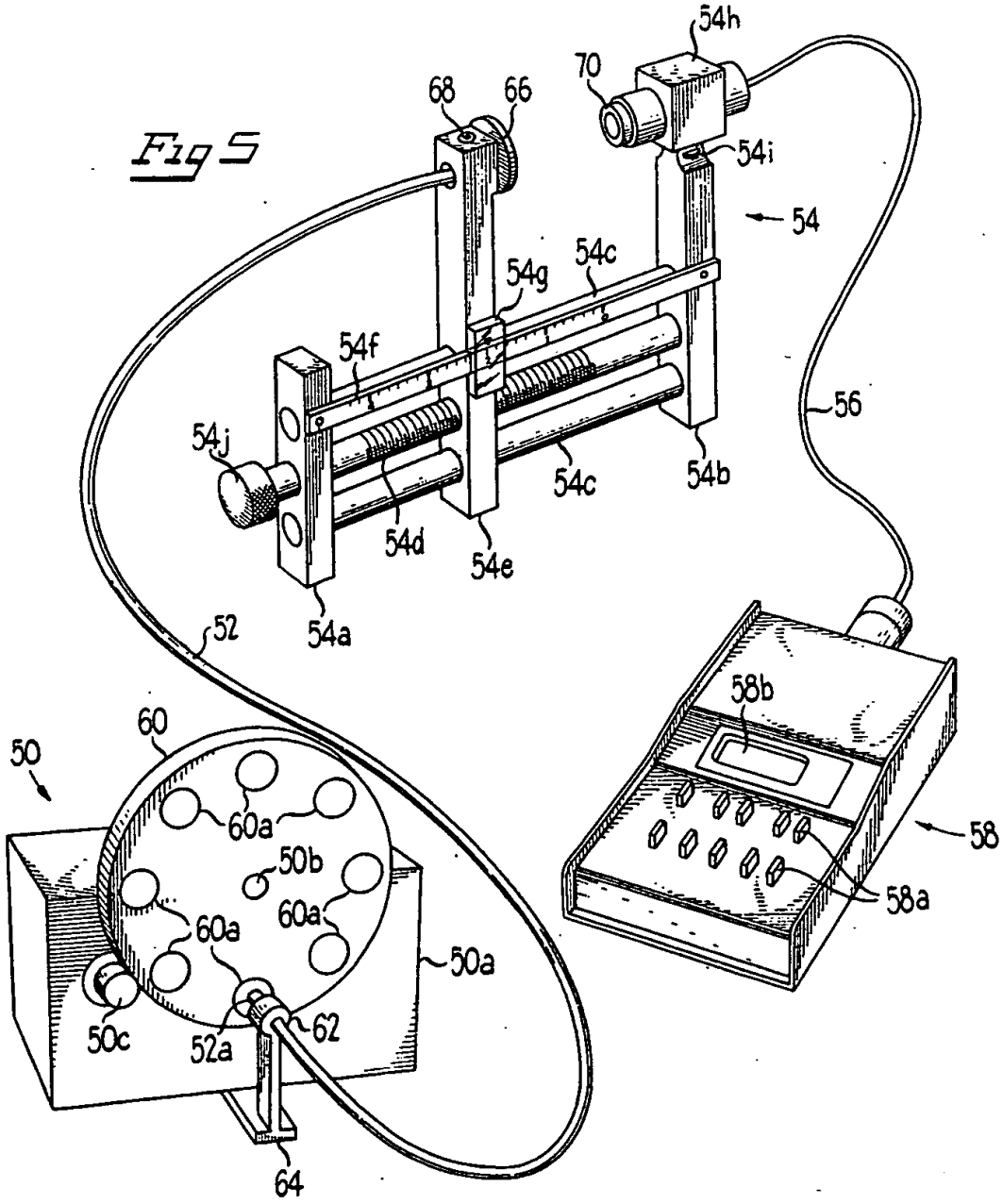


Fig 5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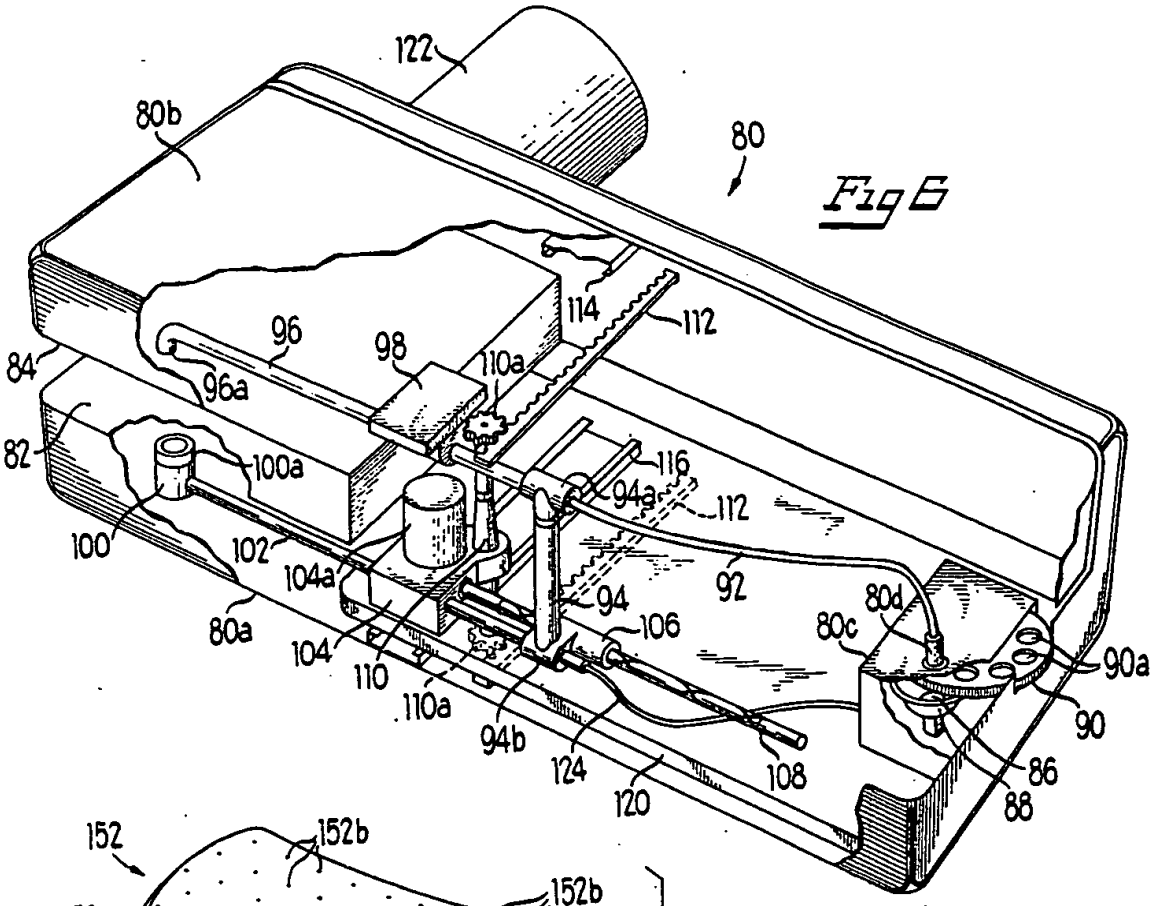
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Fig 6

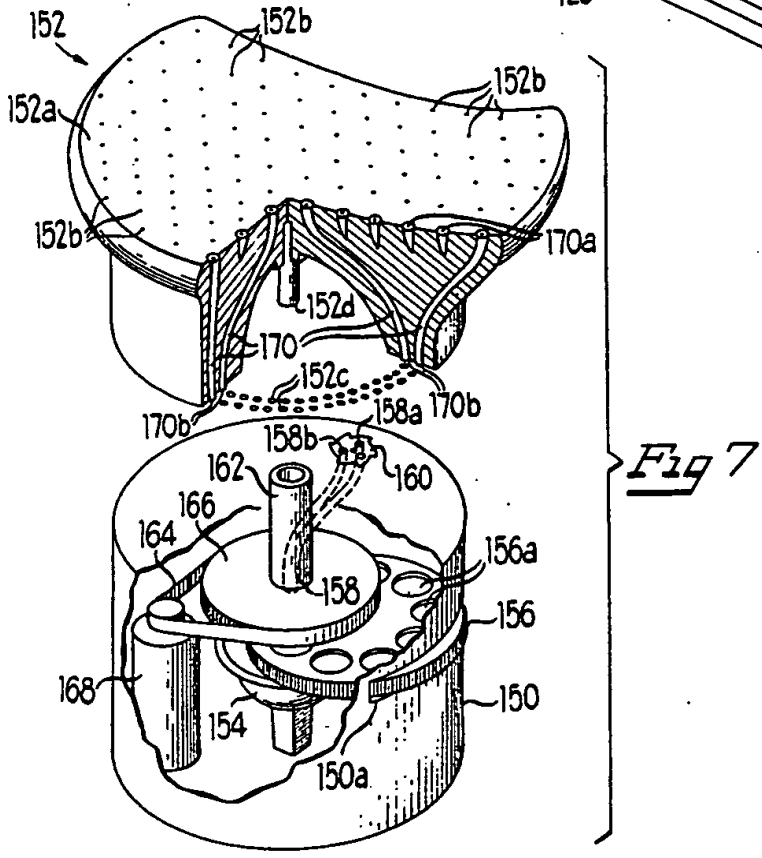
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Fig 7

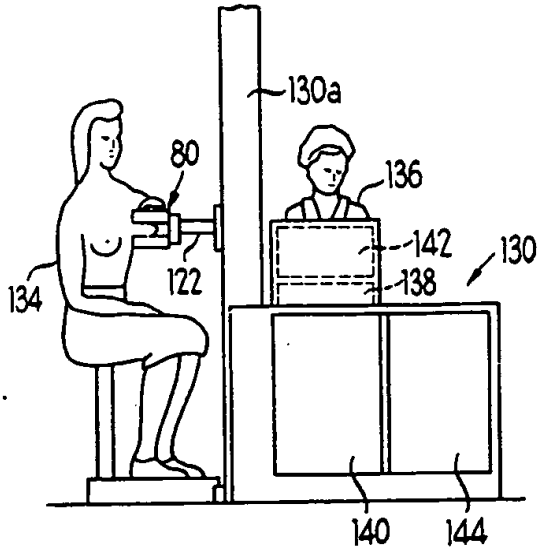

Fig 8A

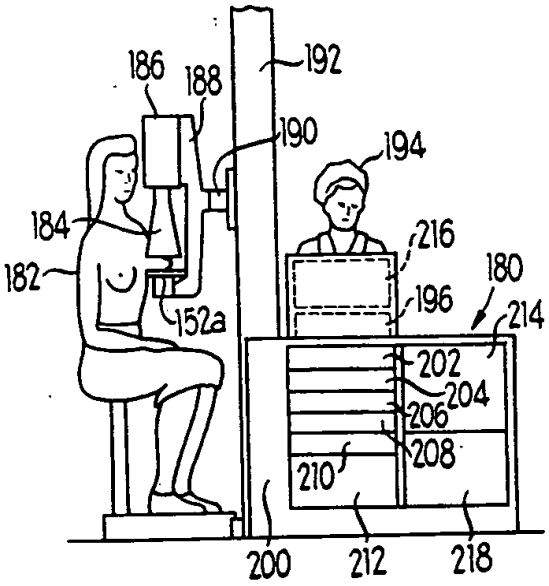

Fig 9A

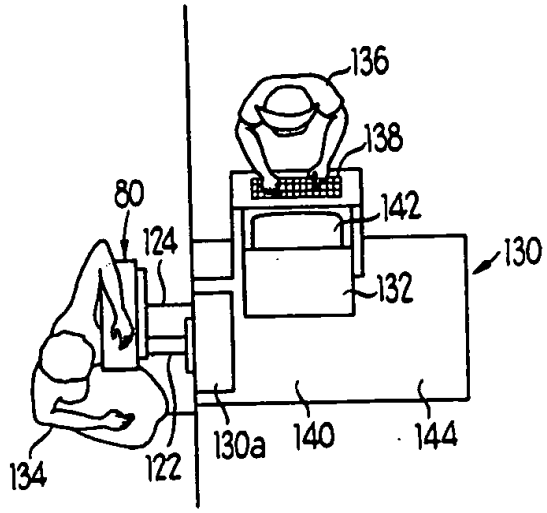

Fig 8B

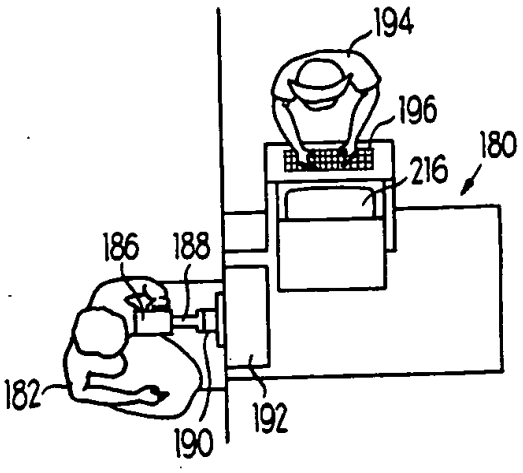

Fig 9B

SPECIFICATION

Apparatus and method for interrogation of biological materials

The present invention relates to a device and method for interrogation of biological materials which apparatus may include means for the quantitative measurement of the absorption, refraction, and scatter, as a function of wavelength, of biological tissue, especially living human tissue, utilizing non-ionizing radiation.

Present methods of interrogating human tissue to detect the internal structure underlying the tissue have employed various x-ray, computerized axial tomographic x-rays, thermographic, and ultrasonic wave techniques. While x-rays yield good images of internal body structure, they rely on ionizing radiation which entails a carcinogenic risk to the patient. The risk is of special importance in the detection of breast lesions. Wholly apart from the radiation dosimetry risks associated with the use of x-rays, the utilization of x-rays is inefficient from an energy standpoint. More specifically in this connection, a conventional x-ray tube consists of an anode-and-cathode assembly placed in an evacuated glass envelope. The anode is usually a massive piece of copper in which is placed a small tungsten target. The cathode assembly generally consists of a filament of tungsten wire placed in a shallow focusing cup. The hot tungsten filament provides the source of electrons which are accelerated toward the anode by applying a high voltage between the anode and cathode. Even in the most favourable cases, the active radiation output of such an assembly is one or two percent of the total electron energy. In other words, most of the energy is dissipated in the target as collisional energy or heat. In addition to the foregoing shortcomings of x-ray techniques in tissue interrogation, proper shielding and direction of an x-ray beam with the use of a diaphragm and ports are required to obtain a usable film exposure or a satisfactory treatment.

The use of thermographic techniques in the interrogation of human tissue while employing non-invasive infrared energy has a number of shortcomings which make is unsatisfactory as a diagnostic tool, particularly in the case of human breast lesions. In the case of breast lesion detection, thermography, alone, generally is not relied upon, and is usually supplemented and used in conjunction with mammography. One reason for using x-ray techniques along with thermographic practices to detect breast lesions centers on the problem of maintaining a machine employing thermographic techniques sufficiently stable for quantitative and reproducible measurements. The large gain in the amplification required in converting the radiant infrared energy into a display makes the system very susceptible and sensitive to system drift. The slight drift in the sensitivity of the detector will result in a change in the intensity of the display with respect to the temperature of the surface being scanned. Wholly apart from the aforementioned problem, it is required to use a coolant such as liquid nitrogen to maintain the temperature of the radiant energy detector within usable temperature ranges. This aspect of the technique entails the use of substantial amounts of energy to sustain a temperature of −198°C, the temperature at which nitrogen is in a liquid state. Thermography has the further disadvantage of being unable to detect and locate small lesions in the thick living tissue such as the human breast. In this connection, insufficient infrared radiation is emitted by such small bodies to enable the infrared sensing unit of such equipment to detect any appreciable change in tissue temperature caused by such small bodies.

Ultrasonic techniques are limited in application by attenuation and interaction of ultrasound waves with the tissue being interrogated. In addition, ultrasound poses certain biological hazards such as platelet aggregation which is exhibited at power levels less than those causing thermal injury.

In accordance with the present invention, apparatus and a method have been evolved for the non-invasive examination of living human tissue which effectively eliminates the hazards involved in the use of x-rays and ultrasonic techniques, and which overcomes the problems inherent in the use of thermographic diagnostic techniques. The present invention is directed to the quantitative measurement of visible and infrared light transmission and reflection, and involves passing light of various selected wavelengths through tissue being studied and measuring the intensity of light transmitted or reflected relative to the intensity of the light sent thus enabling a measurement of the refractive index, absorption, and scatter of the tissue. The invention takes advantage of the fact that various types of tissues such as fat, muscle and tumor differ significantly in absorption, refraction, and scattering characteristics with respect to visible and infrared light. The contrast elicited between various tissues can be increased by selecting the wavelengths used for measurement. Information regarding tissue type and metabolic state can be obtained by measuring the amount of light transmitted or reflected at various wavelengths, and comparing these values with norms or standards previously established by direct measurement in human patients who subsequently have biopsy documentation of the nature of the tissue examined. In one of its forms, the device of the present invention utilizes a detector array to differentially record the photon flux in the central area which corresponds to that portion of the detector which is maximally illuminated by the light beam when tissue is not interposed to serve as scattering medium, and one or more concentric rings of active detector surface which receive light which has been scattered to various degrees away from the central detector. This arrangement allows separate recording of central and peripheral zones thereby providing additional information regarding intensity of scattering as well as the degree of refraction and absorption at that particular

wavelength. Information from each of these concentric detectors is recorded separately and is available for further manipulation such as the creation of ratios. In the simplest form, this embodiment of the invention comprises a central detector of dimensions of the unscattered beam and one or more concentric peripheral detectors. An alternative embodiment is an electronic detector array of multiple elements such that a tissue-scatter-signature map may be produced which is specific to transillumination of water, blood, fat, muscle, breast cancer, skin, flecks of calcium, and other simple and complex transillumination elements. Such complex tissue signatures can be stored in digital or analog memory and can be compared with freshly received signals. Changes in the scatter ratios can be used as a signal in imaging and non-imaging systems.

In accordance with another aspect of this invention, scanning quantitative transmission or reflection of visible or infrared light to produce a shadowgraph image is employed. In this form of the invention, the above-described quantitative transmission or reflection system is sequentially scanned across the tissue being investigated to build up an image in a point-wise fashion. The scanning advantageously is carried out by conventional rectilinear techniques utilizing a photo-exposure device mechanically coupled to the light source and dectector unit. Alternatively, photographic recording can be obtained by electronically coupled the XY position of the scanning arm with the XY location of the electron beam of a cathode ray tube in connection with time exposure of the photographic film. In such an electronic configuration the XY position of the beam is determined by the XY position of the scanning head and the intensity of the electron beam current is proportional to the number of photons sensed by the detector head.

A still further aspect of the invention involves the quantitative transmission and reflection of visible and infrared light at specific wavelengths to emphasize the distinction between various tissues in conjunction with a digital memory or an image storage tube such that image multiplication, division, addition, or subtraction can be performed in a digital form with digital memory or in analog form on an image storage tube. The individual images carried by various wavelengths can be displayed in a multi-spectral imaging process which can be displayed in a gray scale modality or in a color display in which image data at a specific wavelength is assigned to a specific color gun in a three beam color video display. Through multi-spectral processing techniques the distinction between different tissues or different components in tissue or physiologic information such as the oxidation state of various portions of tissues can be demonstrated and recorded.

In an additional aspect of the invention, a computer aided reconstruction is utilized which is based on multiple images each of which has been produced from a different tranmission or reflection light point source. The computerized reconstruction and processing method is analogous to that used in computerized axial tomographic systems of the type currently employed with x-rays. The tissue under examination is illuminated from a multiplicity of points by either moving light or an array of switched sources. The imaged patterns formed by illumination from each point is sensed by an appropriate detector system such, for example, as the Hammamatsu infrared vidicon, and processed for field uniformity correction prior to being stored in an electronic memory. The imaged patterns are stored in conjunction with the XY coordinates of the originating transillumination light point. These imaged patterns are processed by being mathematically back projected to yield a tomographic set of images. One advantage of this system is that the spacial relationship of objects can be ascertained in depth, and resolution is much higher with a greater photon efficiency than can be achieved in a rectilinear scanning mode.

The apparatus of the present invention, in its basic form, comprises a light source, light detection means, and a signal display means. In its more sophisticated form, the device of the present invention includes a light source, wavelength selection means, light transmission means, optical alignment means, light collection means, light detection means, signal amplification means, signal comparison means and signal display means. The term "light" as used herein means non-ionizing visible and infrared light having a wavelength in the range of 400 to about 700 nanometers, and 700 to about 10^6 nanometers, respectively. The preferred range is from about 600 nanometers in the visible range to about 1400 nanometers in the infrared range.

The light sources used in the practice of the invention include a quartz-halogen tungsten filament projector bulb, a zenon arc lamp, a xenon-mercury arc lamp, light-emitting diodes, tunable lasers, or ordinary light. The wavelength selection means employed advantageously comprises broad or narrow band thin film optical filters with peaks ranging from about 450 nanometers through about 1350 nanometers at 50 nanometer intervals. One or more monochromators may also be advantageously used. The light delivery of transmission means employed include flexible fiber-optic bundles, rigid light guides or pipes, said means being capable of transmitting the wavelengths of interest. The detector means used include silicon or germanium photodiodes, photomuliplier tubers, vidicons, and the like.

The foregoing, and other features and advantages of the invention, will become clear from the following description and claims taken in conjunction with the accompanying drawings wherein:

Fig. 1 is a representation of the propagation of light through relatively homogeneous human tissue illustrating the effect of interaction of the light with a solid absorption body in the tissue, the wave forms illustrated being isoluminance lines;

Fig. 2 is similar to Fig. 1 except that the solid

absorption body is at a greater distance from the light entry point;

Figs. 3 and 4 are top and side views, respectively, illustrating light entering at two different points to produce isoluminance lines which are projected as shadow patterns in Fig. 3;

Fig. 5 is a view in perspective of one embodiment of the apparatus of the present invention;

Fig. 6 is a view in perspective, partly broken away, illustrating an embodiment of a rectilinear scanner head for practicing the present invention;

Fig. 7 is an exploded view, partly in section, of a light delivery unit for supporting and transmitting light through a human breast;

Figs. 8A and 8B are side and top views, respectively, of an embodiment of apparatus utilizing a rectilinear scanner head of the type shown in Fig. 6 in conjunction with a cathode ray tube set up for interrogating the human breast; and

Figs. 9A and 9B are side and top views, respectively, illustrating the light delivery unit shown in Fig. 7 used in conjunction with computerized axial tomography apparatus for interrogating a human breast.

At the outset, it should be mentioned that it has been demonstrated that biological materials manifest comparatively good transparency in the infrared region of the spectrum to permit sufficient photon transmission through human tissue being examined to enable detection of events even in areas of substantial thickness. Thus, Frans F. Jöbsis, in an article entitled "Noninvasive, Infrared Monitoring of Cerebral and Myocardial Oxygen Sufficiency and Circulatory Parameters" published in Science, December 23, 1977, Volume 198, pp. 1264—1267, stated "the relatively good transparency of biological materials in the near infrared region of the spectrum permits sufficient photon transmission through organs examined for the monitoring of intracellular events." The Jöbsis article dealt with the monitoring of tissue oxygen sufficiency. By utilizing strong light sources and a photomultiplier tube, Jöbsis was able to detect infrared light traversing 13 centimeters of human brain through the skull and scalp.

Referring, now, more specifically to Fig. 1 of the drawings, the propagation of visible red or infrared light through relatively homogenous tissue which is intensely light scattering and which contains a light absorbing object is illustrated by wave forms which shall be called isoluminance lines. Light enters the tissue 10 at 12 as a narrow collimated monochromatic beam. Isoluminance line 14a defines the outlines of equal luminosity which have been produced by light input at point 12. Isoluminance lines 14b and 14c represent isoluminance line contours at increasing distances from the original light input at point 12. Isoluminance line 14d represents the distribution of light intensity after interaction with a light-absorbing object 16. Isoluminance line 14e depicts the gradual filling-in process of the shadow cast by the light-absorbing object 16 due to intense scatter within the tissue 10. Isoluminance line 14f, at considerable distance from the light input point 12 and the light-absorbing object 16, has a shallow depression 18 in the isoluminous contour caused by the light absorption by object 16. The center of the depression 18a is caused by absorption by the light-absorbing object 16 and represents a luminosity minimum, while the rim 18b of the depression represents a luminosity maximum. A detector such as a silicon photodiode or silicon photodioide array (not shown), placed on the opposite side of the tissue 10 from the light input point 12 overlying the depression 18 in the isoluminance line 14f, enables a measurement to be made of the light transmission through the tissue 10 as affected by the light-absorbing object 16. A detector of sufficient size to have a separate sensitive surface covering the areas 18a and 18b of the depression 18 would provide a meaningful ratio between the luminosity at 18a and 18b to enable the object 16 to be detected.

Fig. 2 is similar to Fig. 1 except that the light input point 20 is at a greater distance from the light-absorbing object 22. As before, the light input generates a series of isoluminance lines 24a, 24b, 24c, 24d, 24e, and 24f before interacting with the light-absorbing object 22. Line 24g represents the distribution of light intensity after interaction with light-absorbing object 22. Since the light-absorbing object 22 is close to the upper surface of the tissue 10, the depression 26 in the isoluminance line 24h is quite large compared to the situation depicted in Fig. 1 in which there was a greater distance between the object 16 and the upper surface of the tissue 10. In the representation of Fig. 2, there is a greater difference between the level of light at the edge 26b of the depression 26 as compared with the center 26a of the depression. Detection of the object 22 can be achieved as described in connection with the description of Fig. 1.

Figs. 3 and 4 are side and top view representations of isoluminance lines produced in a section of intensely light scattering tissue 30, having two different light-absorbing objects 32 and 34, when light in introduced at two points 36 and 38. The isoluminance lines emanating from point 36 are shown in broken lines, while the isoluminance lines emanating from the point 38 are shown in solid lines. The lines 36a, 36b and 36c emanating from the point 36 provide, as before, a depression 40 which is detectable as indicated at 32a in Fig. 3. However, the isoluminance lines 36a, 36b, and 36c also fan out laterally in the direction of the object 34 and form a depression 42 which is detectable as a shadow of the object 34 are represented by 34' in Fig. 3. Similarly, isoluminance lines 38a, 38b, 38c, 38d, and 38e emanating from point 38 provide a detectable depression 44 as a result of the absorption of the light by the object 34. The shadow 34a thus produced is detectable as represented in Fig. 3. As in the case of the isoluminance lines emanating from point 36, the

isoluminance lines 38a, 38b, 38c, 38d, and 38e from point 38 are intercepted and absorbed by the object 32 to prodice a depression 46 which is detectable as a shadow 32' as shown in Fig. 3. Thus, it is possible not only to detect the presence of the two objects 32 and 34 in the tissue 30, but, also, to precisely pinpoint the areas in the tissue 30 where they are located, by back projection means.

The embodiment of the apparatus of the present invention illustrated in Fig. 5 comprises a light source and wavelength selection member 50 connected by a flexible fiber-optic bundle or light guide 52 to a photosensor carrying member 54 which, in turn, is connected by a cable 56 to a digital photometer readout member 58. The light source and wavelength selection member 50 includes a housing 50a in which a source of infrared light such as a quartz halogen tungsten lamp (not shown) is positioned. A variable intensity control knob 50c is provided on the housing 50a for controlling the intensity of the beam emitted by the lamp. A filter wheel 60 is rotatably mounted on the housing 50a by a shaft 50b. The wheel 60 desirably comprises a plurality of concentrically arranged broad band, thin film interference filters 60a each advantageously having a different peak ranging from 450 nanometers to 1350 nanometers at 50 nanometer intervals. Narrow band filters may be employed to further discriminate among processes detected with the apparatus. The entrance facet 52a of the fiber-optic light guide 52 is maintained in position with respect to the lamp and a selected one of the filters 60a by a collar 62 joined to a standard 64 attached to the base of the housing 50a.

The photosensor carrying member 54 as illustrated comprises a short, stationary end post 54a and a long, stationary end post 54b maintained in fixed, spaced apart relation by a pair of smooth surfaced rods 54c—54c and an externally threaded rod 54d having an adjusting knob 54j. A movable post 54e is positioned between the posts 54a and 54b, and is adjustable in either direction on the rods 54c—54c and 54d by turning the knob 54j. A suitably scaled measuring device 54f is secured at its ends to the stationary posts 54a and 54b. An indicator 54g is secured to the movable post 54e, and is adapted to slide along the markings on the device 54f as the post 54e is moved. The outlet end of the fiber-optic light guide 52 passes through a bore in the outer end of the movable post 54e, and is secured in a disc 66. A set screw 68 maintains the outlet end of the guide 52 in position with relation to the post 54e. The long stationary post 54b has an adjustable head 54h which carries a photosensor in the form of a solid-state photodetector 70 of the silicon photodiode type. The head 54h is provided with a knurled adjusting screw 54i to enable the photodetector 70 to be aligned with the outlet end of the fiber-optic light guide 52. The input cable 56 connects the photodetector 70 to the digital photometer readout member 58. The member 58 has selection buttons 58a for determining the display factors which are visible through a window positioned over a liquid crystal display 58b.

In utilizing the apparatus shown in Fig. 5, a human breast having a palpable lump is comfortably compressed between the disc 66 and the photodetector 70. The measuring device 54f will indicate the exact distance between the outlet end of the light guide 52 and the photodetector 70, and, therefore, the thickness of the tissue being traversed by the light from the source located in the housing 50a. Readings are obtained on the readout member 58 by passing light, at different wavelengths, from the source through the lump in the breast. Using the same wavelengths, light from the source is then passed through an area, or areas, of the breast away from the lump. Since the degree of light scattering and absorption at specific wavelengths by a cancerous body is far greater than that of benign bodies and healthy, fatty tissue, the nature of the palpable lump can readily be ascertained from the information displayed by the readout member 58.

Referring, now, to Fig. 6 of the drawings, the embodiment of the rectilinear scanner head illustrated, and designated generally by reference numeral 80, comprises a lower, stationary portion 80a and an upper movable portion 80b which is vertically adjustable with relation to the portion 80a. The portions 80a and 80b at one end define a pair of parallel plate members 82 and 84 between which a human breast to be examined is compressed. The lower portion 80a of the scanner head 80 is provided with a housing 80c in which is positioned a source of infrared light such as a quartz halogen bulb 86 associated with a reflector 88. A rotatable filter wheel 90 is mounted on a shaft above the bulb 86 and the reflector 88. The wheel 90, like the wheel 60 of the apparatus shown in Fig. 5, is designed to house a plurality of concentrically arranged narrow or broad band optical filters 90a in cavities along the perimeter. An area of the wheel 90 extends through a recess or slot formed in the rear wall of the scanner to enable an operator to readily select any desired filter 90a for tissue interrogation purposes. Light from the bulb 86 passes through a selected filter 90a and enters the entrance end of a flexible fiber-optic bundle 92 held in position on the housing 80c by a fitting 80d. The exit end of the optic bundle 92 is secured in a coupling 94a positioned on the upper end of a post 94. The coupling 94a also receives the entrance facet of a rigid light pipe 96 which slides in an alignment member 98 and which terminates at the lower or breast engaging surface 84 of the adjustable upper plate member 80b of the scanner head 80. The exit facet 96a of the light pipe 96 advantageously is provided with a variable aperture (not shown) to enable the diameter of the light beam traversing the optic bundle 92 and the light pipe 96 to be regulated at the exit facet 96a of the light pipe 96. Positioned below and in opposed relation to the exit facet 96a of the light pipe 96 is a photoreceptor 100 provided with a variable

aperture 100a for controlling the diameter of the light beam entering the photoreceptor 100. The photoreceptor 100 desirably is a silicon photodiode and is mounted on the end of an alignment shaft 102. The shaft 102 passes through a bore in an alignment member 104 and is received in an integral coupling 94a provided at the lower end of the post 94. The coupling 94 b is secured to an internally grooved sleeve 106 which receives an externally grooved drive shaft 108. The shaft 108 is driven by a motor 104a carried by the alignment member 104, and is grooved to form a combined clockwise and counterclockwise helix such that, upon completion of its travel in either direction along the drive shaft 108, the sleeve 106 will automatically reverse its direction of travel. As the shaft 108 rotates, the post 94, the light pipe 96 and the photoreceptor 100 are simultaneously moved in the same direction of travel as the post 94 assembly. At each fore and aft travel end point, an escapement or switch (not shown) moves the light pipe 96, shaft 102, and alignment members 98 and 104, a precise amount on the slide guides 114—116, through an indexing rotation of the gears 110a—110a on the gear tracks 112—112. Each end of the gear shaft 110 is provided with a gear 110a—110a which travel on the parallely arranged gear tracks 112—112. Thus, a two dimensional surface can be interrogated by the fore and aft, and lateral travel of the exit facet 96a of the light pipe 96 and photoreceptor 100 in response to the motion of the drive shaft 108 and the gear shaft 110.

The breast engaging surfaces of the plate members 82 and 84 desirably are formed of a clear plastic to enable the exit facet 96a of the light pipe 96 and the variable aperture 100a on the photoreceptor 100 to move with relation to the breast without making direct contact with it.

Alignment of the movable elements of the head 80 is maintained by the aligned parallely arranged tracks 114 and 116, respectively. The entire upper portion 80b of the scanning head 80 can be moved vertically relative to the lower portion 80a so as to accept substantially any size breast. The post 94 and the shaft 110 are splined to allow free up and down movement from a distance of about one inch to four inches. A manually driven toothed power transmission belt 120 is connected to height adjustment screws (not shown) positioned at the corners of the scanning head 80 to enable the space between the clear plastic surfaces of the members 82 and 84 to be adjusted as desired. A shaft 122 is provided for connecting the scanning head 80 to a scanning console 130 (see Figs. 8A and 8B). A cable 124 carries two sets of electronic signals to the imaging console 132. One set of signals relates to the absolute intensity of light sensed by the photoreceptor 100. The other set of signals relates to the absolute XY positional coordinates of the light pipe exit facet 96a and the photoreceptor variable aperture 100a. These sets of electronic signals provide intensity modulation to a CRT beam and location control to that beam. As shown in Figs. 8A and 8B, the breast of a patient 134 is compressed in the scanning head 80 which is connected by the shaft 122 to a support column 130a. An operator 136 communicates by a keyboard 138 with the control electronics 140 to produce an image and alpha-numeric display on cathode ray tube 142. Images on photographic film are produced by a multiformat imager 144.

In Fig. 7 of the drawings, there is shown a light transmitting apparatus comprising a base member 150 and a breast supporting member 152. The member 150 carries a light source such as a quartz halogen bulb (not shown) positioned in a reflector 154. A filter wheel 156 is rotatably mounted above the reflector 154 is provided with a plurality of optical filters 156a concentrically arranged around the perimeter thereof. A portion of the outer margin of the wheel 156 extends outwardly through a slot 150a formed in the side wall of the member to facilitate rotation of the wheel. A light pipe 158 having a light entrance facet positioned adjacent to the filter wheel 156 in opposed relation to the light source is carried in the member 150. The light pipe 158 is branched to provide two light exit facets 158a and 158b which are shuttered by a toothed aperture wheel 160. The light pipe 158, its light exit facets 158a and 158b, and the aperture wheel 160 rotate about a hollow shaft 162 driven by a belt 164 connected to a drive disc 166 and a motor 168. The member 152 is provided with a downwardly extending rod 152d which is received in the hollow shaft 162 of the member 150. The member 152 is contoured to enable a patient to be comfortably examined. The upper surface 152a of the member 152 has a plurality of evenly spaced light point apertures or orifices 152b formed therein. Each of the orifices 152b is aligned with the light exit facets 170a of an equal number of fiber-optic light delivery bundles 170. The light entrance facets 170b are arranged adjacent spaced rows of openings 152c formed in the bottom surfaces of the member 152. In operation, the light exit facets 158a and 158b of the light pipe 158, and the apertured wheel 170 are rotated in a manner such that the outer and inner rows of openings 152c, and their associated light entrance facets 170b of the optic bundles 170, are addressed sequentially. A timing signal from the motor 168 is fed to a computerized axial tomographic apparatus 180 (see Figs. 9A and 9B).

As shown in Figs. 9A and 9B, a patient 182 is seated with her left breast compressed between the upper surface 152A of the member 152 and a light excluding cone 184. The computerized axial tomographic apparatus schematically illustrated comprises image receptor means which includes a computer compatible tv camera 186. A yoke 188 maintains optical alignment. A shaft 190 allows rotation about the axis and vertical movement is possible along a support column 192. An operator 194 manipulates a keyboard 196 for communicating with the computer and to display images and alpha-numerics on a cathode ray tube. Computer system 200 consists of several modules

including a video analog-digital converter 202, a camera-computer interface 204, and a frame storage unit 206. The frames 208 are operated upon by a uniformity connection module 210, and are passed to frame memory 212. When the family of images coded to the light points from exit facets 170a of the member 152 have been acquired, an image reconstruction algorithm 214 operates upon these frames to create a computer reconstructed back projected image. This image is displayed on a television image display monitor 216, and is simultaneously displayed on a high resolution video screen of a multiformat film imager 218 which serves to produce transparency images of the breast on the member 152 similar in appearance to conventional mammograms.

While the invention has been disclosed and described with relation to its utilization in the detection of human breast lesion, it should be understood that the invention can also be used to monitor the changing optical absorption and scatter characteristics of light in the lungs and other accessible tissues and to image lungs and brains as well as other portions of the body.

CLAIMS

1. Apparatus for interrogating biological materials comprising a source of non-ionizing electromagnetic radiation; means for applying the radiation from said source to a biological material to be interrogated; and means for detecting quantitatively the radiation absorption and scattering characteristics of said material.

2. Apparatus according to claim 1 wherein said detecting means comprises a detector having a variable aperture.

3. Apparatus according to claim 1 wherein said detecting means comprises a plurality of independent concentrically arranged detectors, or a detector array.

4. Apparatus according to claim 1 wherein the non-ionizing electromagnetic radiation comprises visible light having a wavelength in the range of from about 400 to about 700 nanometers, or infrared light having a wavelength in the range of from about 700 to about 1×10^6 nanometers.

5. Apparatus according to claim 1 wherein the source of non-ionizing electromagnetic radiation is a quartz-halogen tungsten filament lamp, xenon arc lamp, or an xenon-mercury arc lamp.

6. Apparatus according to claim 1 wherein the source of non-ionizing electromagnetic radiation is a light emitting diode.

7. Apparatus according to claim 1 wherein the source of non-ionizing electromagnetic radiation is a tunable laser beam.

8. Apparatus according to claim 1 wherein wavelength selection means is provided between the source of electromagnetic radiation and biological material under interrogation.

9. Apparatus according to claim 8 wherein the wavelength selection means comprises at least two thin film optical band pass filters.

10. Apparatus according to claim 8 wherein the wavelength selection means comprises at least one monochromator.

11. Apparatus according to claim 9 wherein said filters comprise broad band thin film interference filters having peaks ranging from about 450 nanometers to about 1350 nanometers at 50 nanometer intervals.

12. Apparatus according to claim 9 wherein said filters are carried on a rotatable wheel which is positioned adjacent to the source of electromagnetic radiation.

13. Apparatus according to claim 1 wherein radiation transmission means is provided to transmit electromagnetic radiation from said source along a predetermined path to the biological material.

14. Apparatus according to claim 13 wherein the radiation transmission means comprises a flexible fiber-optic light bundle.

15. Apparatus according to claim 13 wherein the radiation transmission means includes a rigid light pipe.

16. Apparatus according to claim 1 wherein the detecting means comprises photon intercepting means.

17. Apparatus according to claim 1 wherein the photon intercepting means comprises a silicon or germanium photodiode, or an array of silicon or germanium photodiodes.

18. Apparatus according to claim 1 wherein the detecting means comprises a photomultiplier tube.

19. Apparatus according to claim 1 wherein the detecting means comprises an infrared light detecting television camera.

20. Apparatus according to claim 19 wherein an electronic color television camera is used as the detecting means.

21. Apparatus according to claim 1 wherein the detecting means includes video disc or computer disc storage means.

22. Apparatus according to claim 1 wherein the detecting means includes an image storage tube.

23. Apparatus according to claim 1 wherein the detecting means includes computerized axial tomography means for constructing a tomographic image of the interrogated biological material.

24. Apparatus according to claim 1 wherein the biological material being interrogated is positioned between the source of the electromagnetic radiation and the detecting means, and the source of electromagnetic radiation and the detecting means are moved by rectilinear scanning means relative to the material being interrogated.

25. Apparatus for interrogation of living human tissue comprising a light source capable of emitting visible light having a wavelength of the order of 400 to 700 nanometers or infrared light having a wavelength of the order of 700 to 1×10^6 nanometers; wavelength selection means through which light from said source can be selectively passed; light delivery means having a light entrance facet positioned adjacent to the wavelength selection means and a light exit facet positioned adjacent to human tissue undergoing

interrogation; and light detection means positioned on the side of said tissue opposite to the side on which the light exit facet of the light delivery means is positioned.

26. Apparatus according to claim 25 wherein the light detection means is positioned on the same side of the tissue on which the light exit facet of the light delivery means is positioned.

27. Apparatus according to claim 25 wherein the light source is a quartz-halogen tungsten filament lamp, a xenon arc lamp, or a xenon-mercury arc lamp.

28. Apparatus according to claim 25 wherein the human tissue is a female breast.

29. Apparatus according to claim 25 wherein the wavelength selection means comprises at least two optical band pass filters.

30. Apparatus according to claim 25 wherein the wavelength selection means comprises at least one monochromator.

31. Apparatus according to claim 25 wherein the light delivery means includes a flexible fiber-optic bundle.

32. Apparatus according to claim 25 wherein the light delivery means includes a rigid light pipe.

33. Apparatus according to claim 25 wherein the light detection means comprises a sllicon or germanium photodiode or a silicon or germanium photodiode array.

34. Apparatus according to claim 25 wherein the light detection means includes an infrared lead sulfide vidicon.

35. Appparatus according to claim 25 wherein the light detection means comprises a video disc, a computer disc, or an image storage tube.

36. Apparatus according to claim 25 wherein the light detection means includes a photomultiplier tube.

37. Apparatus according to claim 25 wherein signal amplification means are provided for the light detection means.

38. Apparatus according to claim 25 wherein signal display means is provided for the light detection means.

39. Apparatus according to claim 38 wherein the signal display means is associated with rectilinear scanning means.

40. Apparatus according to claim 38 wherein the signal display means is associated with computerized axial tomographic imaging means.

41. Apparatus for detecting and locating human breast lesions comprising a source of light capable of emitting visible light having a wavelength in the range of 400 to 700 nanometers or infrared light having a wavelength in the rage of 700 to 1400 nanometers, a rotatable wheel having arranged thereon a plurality of broad band thin film interference filters with peaks ranging from 450 nanometers through 1350 nanometers at 50 nanometer intervals, said wheel being positioned with relation to said light source to enable any selected one of the filters on the wheel to intercept light emitted by said source; a flexible fiber-optic light bundle having a light entrance facet positioned to receive light passing through said any one selected filter and a light exit facet for delivering filtered light from said source to a breast suspected of having a lesion; adjustable breast engaging means, said means including aligned light directing means and light collection means; and light detection means connected to the light collection means for providing an indication of the differential light absorption and scatter characteristics of the area of the breast traversed by the light.

42. Apparatus according to claim 41 wherein the light detection means comprises a photodetector having a variable aperture, concentrically arranged independent detectors, or a detector array.

43. Apparatus according to claim 41 wherein the light source is a quartz-halogen tungsten filament lamp, a xenon arc lamp, or a xenon-mercury arc lamp.

44. Apparatus according to claim 41 wherein the light collection means is a silicon or germanium photodiode.

45. Apparatus according to claim 41 wherein the light detection means is a digital photometer readout unit having a liquid crystal display.

46. Apparatus according to claim 41 wherein the light detection means comprises a photomultiplier tube, or a television camera tube.

47. Apparatus according to claim 41 wherein the light detection means is coupled to a strip-chart recorder for producing a permanent tracing of the absorption and scatter characteristics of the breast tissue.

48. A method of interrogating biological materials comprising providing a source of non-ionizing electromagnetic radiation, applying said radiation at a preselected point, or a plurality of preselected points, to a biological material to be interrogated, and detecting quantitatively the radiation absorption and scattering characteristics of said material by measuring the amount of radiation passing through and/or reflected by said material.

49. A method according to claim 48 wherein the non-ionizing electromagnetic radiation employed is visible light having a wavelength in the range of about 400 to about 700 nanometers, or infrared light having a wavelength in the range of about 700 to about 1×10^6 nanometers.

50. A method according to claim 48 wherein the electromagnetic radiation is passed through wavelength selection means prior to applying it to a biological material.

51. A method according to claim 48 wherein the electromagnetic radiation is applied to the biological material through a restricted aperture thereby to reduce the radiation to a point source.

52. A method according to claim 48 wherein the biological material is a human breast which is maintained in a compressed condition during interrogation.

53. A method according to claim 52 wherein the human breast has a palpable growth within it, and the electromagnetic radiation is applied through a restricted aperture to the breast at the approximate center of said growth.

54. A method according to claim 48 wherein photon interceptor means is provided for the quantitative detection of radiation passing through the biological material, said photon interceptor means being connected t › electronic means for providing a readable image pattern corresponding to radiation absorption and scattering characteristics of the biological material.

55. A method according to claim 48 wherein the biological material is positioned at a point remote from the source of the electromagnetic radiation, and the radiation is conveyed to its point, or points of application to the biological material by flexible light transmission means.

56. Apparatus for interrogating biological material substantially as hereinbefore described with reference to and as illustrated in Figure 5, Figures 6, 8A and 8B, or Figures 7, 9A and 9B.

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